EFFECT OF FLY ASH ADDITION ON THE PROPERTIES OF FIRED CLAY

A thesis in the partial fulfilment of the requirements for the degree of

BACHELOR OF TECHNOLOGY
IN
CERAMIC ENGINEERING

By

UTSARGA CHOUDHURY

111CR0095

DEPARTMENT OF CERAMIC ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA

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May 2015

NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA

CERTIFICATE

This is to manifest that this project report ennobled, "***Effect of Fly Ash Addition on the Properties of Fired Clay***", being submitted by Mr.**Utsarga Choudhury (Roll no. 111CR0095)**, Department of Ceramic Engineering, National Institute of Technology Rourkela, as partial fulfilment of the requirements for the Degree of **Bachelor of Technology Degree in Ceramic Engineering** is a record of unquestionable work carried out by him under my guidance. The results of investigations introduced in this report have been verified and found to be more than satisfactory.

To the best of my cognition, the matter embodied in the thesis has not been presented to any other University / Institute for the award of any Degree or Diploma.

Skpratihar
26.6.15

Prof. Swadesh Kumar Pratihar
Associate Professor
Department of Ceramic Engineering
National Institute of Technology,
Rourkela

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Utsarga Choudhury
26.06.15

25th Jun 2015

Utsarga Choudhury

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ABSTRACT

The disposal of industrial wastes becomes one of the primary environmental problems in the world as these residues make the environment unfriendly and becoming toxic. Fly ash is one of the many substances that causes air, water and soil pollution. It also contains high amounts of toxic metals that might have negative consequences on human health. This waste material to be disposed of is a matter of great concern from the viewpoint of the environmental and ecologic system. Hence, it becomes crucial to reuse the vast amount of fly ash. A lot of research has been done on recycling and how the waste can be reused that we produce in our daily experiences. In order to save the precious land and soil from being used in manufacturing building bricks and to save the environment from the waste, this project work emerges. In this project, the experiment has been done to know whether fly ash addition alters the properties of fired clay or not. Different batches have been made by changing the fly ash percentage which varied from 0% to 80%. After preparation of green bodies drying shrinkage, rolling limits of different batches are analysed. Then products were fired following to that the characterizations i.e. apparent porosity, water absorption, bulk density and firing shrinkage were done. These properties are studied with respect to temperature and fly ash content.

Keywords: Fly ash, clay, apparent porosity, water absorption, bulk density and firing shrinkage, drying shrinkage, rolling limit

CHAPTER 1

INTRODUCTION

Fly ash is also known as flue-ash. It is one of the residues that are generated during the combustion process. It rises with flue gas that contains very fine particles. Fly ash is typically collected with the help of electrostatic precipitators before the reaching of flue gases to the chimneys of coal-fired power plant. After collection, it undergoes rapid settlement when it is suspended in the exhaust gas. Fly ash is spherical in shape, and the range is in between 5 to 300 micrometre due to the rapid solidification. Then it travels through rapid cooling, so few materials do not get time to crystallize, and it becomes amorphous glassy phase. But some refractory phases present in the coal do not undergo complete melting leading to giving some crystalline phase in fly ash. Hence fly ash is a heterogeneous material.

SiO_2, Al_2O_3, Fe_2O_3 and sometimes CaO are the main components of the fly ash. The main phases present in it are a glass phase formed by combining quartz, mullite and the iron oxides. Other phases often identified are cristobalite, anhydrite, free lime, periclase, calcite, halite, rutile, etc. Fly ash can be divided into two classes i.e. class F fly ash, and class C fly ash. The significant difference between the two types of fly ash is the amount of calcium, silica-alumina and iron content. The chemical properties of fly ash depend on the chemical content of coal burnt. Fly ash contains toxic material that is dangerous for human health. It also pollutes the air, water and the environment. Hence, it should be reused rather than keeping it outside as dump material.

Fireclay is one type of refractory clay that is used for manufacturing of ceramics, mainly fired bricks. It is also known as hydrous alumina-silicate with or without free silica. High-grade fire clays can withstand temperatures of 1775 °C. Typical fired clay must withstand a temperature 1515 ^{0}C. The fired clay ranges from flint clay to plastic clay. But semi-flint and semi plastic clay also exist. Fired clay consists of argillaceous materials i.e. kaolinite group of clays, fine-grained quartz and micas, many other organic materials and sulphur compounds. Fusion point of clay is more than 1600 ^{0}C due to which it is resistant to heat. Hence, it is best for the lining furnaces as fired bricks. It can be used to make complex items of pottery due to its stability while firing in the kiln. The chemical compositions of fired clay are 50-60% SiO_2, 23-34% Al_2O_3, 6-27% ignition on loss and few amounts of Fe_2O_3, CaO, MgO, K_2O, Na_2O, and TiO_2.

The combination of both fly ash and fire clay can enhance the refractory properties of the sample. To proceed in that direction this project work come into play to check whether the sample of new composition shows similarity or any changes in the properties that a fire clay poses.

Chapter 2 contributes an abbreviated sketch on the literature studied, in order to find proper composition of fly ash and clay to reduce the amount of clay in making fired bricks as well as to reuse the waste materials. Chapter 3 provides an outlook on the objective of the present study of the project. Chapter 4 provide details for the experimental methods and techniques followed in the present study. Chapter 5 talks about the results obtained by the series of experiments and efforts to arrive at a discussion out of the results. Chapter 6 concludes the observations of the present work.

CHAPTER 2

LITERATURE REVIEW

Study on fired bricks with replacing clay by fly ash in high volume ratio has been done by **Xu Lingling et.al. [1],** wherein it is extracted that fly ash is normally in wet condition that is very low in quality. That low-grade fly ash can be used as raw material to substitute clay to make Firefly ash-clay bricks. The effect of fly ash on firing parameters and properties of blocks were studied by replacing the high amount of clay. Saving the precious land and soil is effective by replacing clay bay fly ash as raw materials at a great extent. The sintering temperature of fly ash-clay bricks goes to 1050^0C that is 50-110^0C higher than that of fired clay bricks by replacing the large amount of clay by fly ash. It is difficult for the mixture of clay and fly ash to meet plastic extrusion as plastic indices are less for the mixture of fly ash and clay. With the increase of fly ash content, plasticity index of the mixture of fly ash and clay decrease. Additive A can be selected to increase the plasticity index of the mixture to meet plastic extrusion that is used in most brick making factories. The fired bricks with a high amount of fly ash have high compressive strength; no cracking takes place due to the presence of lime, less water absorption, high speed to efflorescence, high resistance to frost-melting.

Fly ash addition in clayey materials to improve the quality of solid bricks project has been done by Giuseppe **Cultrone et.al [2]** and studied about two different groups of solid blocks having different compositions which are fired between 800 and 1000^0C to find technological quality. Both groups were mixed with five weight percentage of fly ash. The comparison takes place between similar bricks and no added fly ash bricks**.** The textures of the bricks with fly ash have similarity with the textures of those without it, except that the samples are having additive carried spherical fly ash particles having diameters ranging from 0.1 to10 micrometre. The following conclusions can be drawn after examining the characterization of the texture and the petro physical properties of handmade bricks having fly ash.

* Not more than 10 wt. % of fly ash can be used for the types of raw material utilized in this project. It is because the colour is one of the parameters to look for a replacement of damaged bricks in historic buildings. Significant changes in pigmentation and lightsomeness take place bay adding a higher amount of fly ash.

* Bricks do not subject to any axiomatic changes from the point of view of texture except for spherical fly ash particles with diameters ranging from 0.1 to 10 lm that is present. These particles are disseminated in a clayey matrix with a larger or lesser degree of vitrification depending on the type of raw material used and the firing temperature i.e.800, 900 or 1000^0C

* Fly ash does not alter the hydric properties of the bricks, but it makes them lighter. In fact, all the bricks with fly ash have a lower density.

* Though ultrasound velocities are somewhat lower in blocks with respect to fly ash, dynamo-elastic properties are alike in all conditions.

* When fly ash bricks are exposed to salt crystallization cycles fly ash bricks have less damage than conventional bricks. It happens because of the reduction of the surface area of the blocks. Hence, quality of the brick can be enhanced by the addition of fly ash. However blocks with larger amounts of fly ash could be taken for use in the construction of buildings, but only after they have been subjected to a detailed petro physical characterization study. This means that this research will be helpful for many brick-making companies who can consider fly ash as raw material in their production process. This would encourage the recycling of this waste product and help to reduce manufacturing costs.

Engineering properties of clay bricks with use of fly ash has been studied by **Aakash Suresh Pawar et.al [3],** wherein it tells that Blending different properties of fly ash remains in earth material (5-50% by weight, in proportion of dry fly ash to wet clay, at a stage of 5% each) this will from 16 blocks of every extent have been made. The assembling procedure utilizes strategies and hardware like those used as a part of clay brick industrial facilities. The blocks created were up to 10.60% lighter than clay blocks. The blocks produced from fly ash had a compressive quality more than 5 N/mm2 that is more than typical clay blocks. The outcomes are demonstrative of the tasteful execution of Fly ash remains Bricks as burden bearing components. This kind of blocks uses 15% fly ash blending with 85% mud. It along these lines gives an extensive venue for the transfer of fly ash debris in an exceptionally productive, valuable and beneficial way. This outcome is better contrasted with lime blocks and clay blocks. The mechanical property of Fly Ash Bricks has surpassed those of the standard burden bearing clay blocks. Striking among these properties is the compressive quality. The wet compressive quality was 40% superior to anything great quality clay blocks and lime blocks. The water ingestion in the fresh water of fly ash remains clay block of test B3 that contain 15% fly ash and 85% clay assimilates 19.53% of the water about its weight that is attractive. There is proof that the smaller scale essential elements of the surface of fly ash bricks is portrayed by a rougher composition than that of clay blocks. This trademark is accepted to be in charge of the expanded bond quality with mortar. The edges of fly ash bricks are great contrasted with lime blocks and clay blocks. The resistance of the blocks to rehashed cycles of salt introduction demonstrated zero loss of mass and showed great imperviousness to sulphate assault. It implies nil Efflorescence. The fly ash blocks created were around 10.60% lighter than clay blocks. The diminishment in the heaviness of blocks results in an extraordinary arrangement of funds to the customer those outcomes from expanded number of units and decrease in the loads on essential components. The procedure of production of Fly ash remains bricks shows plainly that there are much investment funds to be done amid the making of the blocks.

Strength development in clay–fly ash geopolymer has been studied by **Patimapon Sukmak et.al [4].** This paper exhibits the part of persuasive variables on the quality advancement in a clay–fly fiery debris geopolymer that a silty earth is utilized as fine totals and fly powder, FA is utilized as a pozzolanic material. A fluid antacid activator, L is a blend of sodium silicate arrangement (Na_2SiO_3) and sodium hydroxide arrangement (NaOH). The considered compelling variables are Na_2SiO_3/NaOH proportion, L/FA ratio and warmth conditions. The ideal element for the clay–FA geopolymer is the Na_2SiO_3/NaOH proportion of 0.7 and the L/FA proportion of 0.6. The Na_2SiO_3/NaOH proportion needed for the clay–FA geopolymer is not as much as that of the FA geopolymer because the dirt has high cation retention capacity and afterward assimilates a percentage of the info NaOH. For a given Na_2SiO_3/NaOH content the quality increments with expanding the fluid antacid activator. The abundance information antacid activator causes the precipitation at ahead of schedule stage before the build-up handle in geo polymerization and results in the splits on the FA particles. The overheating (high temperature) and abundance heat length of time cause the miniaturized scale breaks on the examples. The relationship between the quality and warmth vitality is proposed to incorporate the part of heat temperature and span on the geo polymerization. The compressive quality increments with expanding in warmth vitality up to an individual level. Past this level, the examples psychologist and break because of the diminishment in pore liquid, this brings about the quality lessening. The relationship in the middle of quality and warmth vitality can be utilized as crucial for further study on the quality advancement and the blend plan technique for the clay–FA geopolymer with diverse example measurements, dirt minerals, fluid antacid activators, pozzolanic materials and clay:FA proportion.

Fire resistance of fired clay bricks–fly ash composite cement pastes has been studied by **Hamdy El-Diamond et.al [5]** from which it can be extracted that this work expects to explore the impact of substitution of fly ash for homra on the hydration properties of composite bond glues. The composite concretes made out of the consistent extent of OPC (80%) with variable measures of fly fiery debris and homra. The expansion of fiery fly remains quickens the beginning and last sitting time, while the free lime and joined water substance diminish with fly powder content. The fly fiery remains go about as nucleation destinations that may quicken the rate of development of hydration items that fill a percentage of the pores of the concrete glues. The imperviousness to the fire of composite bond adhesives was assessed subsequent to terminating at 250, 450, 600, 800 °C with the rate of ending 5 °C/min with dousing time for 2 h. The physico-mechanical properties, for example, mass thickness and compressive quality were resolved at every terminating temperature. Besides, the stage organization, free lime and microstructure for some chose tests were examined. It can be presumed that the pozzolanic bond with 20 wt% fly fiery debris can be utilized as flame opposing concrete.

The permeability of recycled aggregate concrete containing fly ash and clay brick waste has been studied by **Lan Zong et.al [6].** The amount of development and decimation waste is continually expanding all through the world, and reusing this waste is valuable and necessary for natural conservation. Since the porousness of solid materials is firmly identified with their sturdiness, this paper predominately talks about the penetrability of reused cement made out of fly fiery debris and earth block waste. Different extents of reused coarse totals acquired from dirt block waste were utilized to supplant standard coarse totals. The properties of regular totals and reused totals were examined, and reused totals showed a higher porosity. Also, the quality of the reused cement diminished as a result of the consolidation of reused coarse totals. The porousness of water, air and chloride particles was assessed through water assimilation, water penetrability, air porousness and chloride particle dispersion tests. The outcomes showed that the porousness of water, air and chloride particles expanded when reused coarse totals were utilized. Furthermore, the reused solid containing earth block waste had developed porosity and shown a free glue grid, which may be the explanation behind the expanded penetrability.

has been studied by **Jainhua Li et.al [7]**. This paper exhibits an investigation of the warmth exchange qualities of new development - block workmanship with fly slag squares. Four types of divider specimens were tried to assess their warmth exchange execution. Taking into account the component of the warm conductivity of dirt blocks, RCB (reused solid blocks) and fly slag hinders, a real esteem figuring technique for deciding the warmth exchange coefficient suitable for designing configuration was proposed. By dissecting and contrasting the test qualities and the hypothetical and actual estimations of the test examples, the proposed system was ended up being sensibly right; it utilized RCB rather than ordinary dirt blocks and a composite divider with fly slag squares demonstrated an improved protection impact. New development of block brickwork with fly fiery remains pieces is useful for nature, as well as gives great warm protection.

Orimulsion fly ash in clay bricks—part 1: composition and thermal behaviour of ash were studied by **M Dondi et.al [8]**. A bitumen-in-water emulsion (Orimulsion) is presently utilized as a fuel as a part of a few warm power plants around the world. Orimulsion burning creates a fly powder rich in S, Mg, V and Ni, which is prepared to recoup metals. With a particular end goal to survey the practicality of a reusing in mud block generation, a portrayal of the physico-compound and warm properties of slag was performed by ICP–OES, XRPD, SEM, BET and TGA–DTA strategies. Orimulsion cinder brought about fine-grained (totals of submicronic particles), exceedingly hygroscopic, constituted fundamentally of magnesium sulfate, vanadyl sulfates and magnesium and nickel oxides, and thermally precarious in the typical block terminating conditions. These elements can influence the brickmaking procedure, especially the pliancy of the mud body and its drying and terminating conduct; besides, an activation of sulphates could happen, advancing the development of flowering and/or the SOx discharge amid terminate.

Application of biomass gasification fly ash for brick manufacturing was studied by C. **Fernández-Pereira et.al [9]**. In this paper, we show an introductory study on the production of blocks made of gasification slag. The objective was to think of an item which fulfils two essential necessities: (an) it has lifted rates of fly fiery debris, and (b) it empowers usage of powder with no pre-treatment. We have made blocks by a method for traditional trim and curing systems, utilizing powder rates of up to 20 wt.%. No unique added substances were added to furnish the blocks with worthy mechanical and/or protecting properties. The fly cinder utilized was created as a part of a fluidised bed pilot plant for preparing olive factory cake, a by result of the olive oil industry delivered in vast amounts in a few EU nations.

Some mechanical and natural properties of cinder gasification blocks were contemplated and contrasted and ordinary qualities for business blocks. The outcomes lead us to reason that the blocks could be utilized monetarily as little thickness earth stone work units with a decent warm protecting limit and, in this manner; the potential for business advancement is promising. What's more, the natural advantage of waste gasification added to the slag use makes the general process more appealing.

CHAPTER 3

OBJECTIVE

The importance of waste utilization is raising day by day due to the limitation on the number of dumping landfill sites, and the general disposal methods have made the environment very unfavourable to life and growth.

Fly ash is that one that pollutes air, water and soil sharply. It makes the cut in ecological cycles and helps to have environmental hazards. It also contains high amounts of toxic metals that have adverse effects on human health. On the other hand, Clay is very much famous for farming function but clay is continuously used for making fired clay bricks. Hence, Fired clay refractories should be disallowed to be utilized in building work to a certain extent in order to save enlightens land. Hence, the fresh constructing materials founded on fly ash are urged to be manufactured.

Hence the present work aims to observe the physical properties i.e. rolling limit of batch and sintering, densification behaviour like apparent porosity, bulk density, water absorption and firing shrinkage of fly ash added batches and to check whether these properties of new composition match with that of fired clay or not.

CHAPTER 4

EXPERIMENTAL PROCEDURE

4.1 BATCH CALCULATION

The raw materials that were needed for preparation of samples are

- Terra-cotta clay
- Fly ash

The samples were prepared by altering compositions of the raw materials which is shown in table No. 1.

Raw materials	Weight (%)							
Fly Ash	0	10	20	30	40	50	60	70
Clay	100	90	80	70	60	50	40	30

Table no 1. Samples formulation

4.2 PREPARATION OF FINE CLAY POWDER

First of all terra-cotta soil was collected from Jhirpani river, Rourkela. The clay contains fine clay, water, grits, sands, etc. Sand and grits were to be separated from the clay that was collected. Then the clay was mixed by water to prepare a slurry typically 15-20% solid loading. Subsequently it was stirred to make the slurry flowable. Stirring had to be done either by hand or mechanical stirrer for 50-60 minute. After that, the slurry was filtered through a 200 mesh sieve. It was collected in a bucket, and the upper portion of the bucket was covered with paper so that no foreign material goes into it. Then it was stored for 2 days permit the clay to settle down. So that water came on the top of the sediment.

Afterwards, the water on the top part of the sediment is poured out, and the deposit was kept into a channel tray for drying. Then it is allowed to dry for 1 day. So that it was placed in the oven at 1100C. Hence, we got a dry hard cake of clay which was crushed and ground in the mortar pestle. Finally, fine clay powder was prepared by sieving the ground clay powder through 200 mesh sieve. Similarly, the required fine fly ash powder was collected by sieving through 200 mesh sieve.

4.3 BATCH MIXING

Mixing is a process that is used to ameliorate the chemical and physical uniformity and homogeneity of the mixture. Convection, shear, diffusion are the three mechanisms by which mixing is done.

- Convection carry-over components from one region to another.
- Shear raises the interface between components by deforming their shapes.
- Diffusion interchanges molecules and particles randomly between adjacent microscopic parts in the mixture.

In initial batch, raw materials were segregated chemically and physically. So porcelain mortar was used to abbreviate scale of segregation of the components and to reduce the extent of inhomogeneity in the mixture

Hence, each batch was mixed for 50 minutes which homogenized by shear, convection and diffusion. After mixing, it was transferred to 75 micron i.e. 200 mesh sieve for further sieving in order to make it flow which leads to homogenize it more efficiently.

4.4 ROLLING LIMIT MEASUREMENT

Plasticity is that property of clay which allows this material to cast a plastic body. Whenever a plastic body is compelled to the application of force, it gets deformed, and absolutely conserves that form after the force applied is removed.

- About 8gm of the clay was taken and rolled with the help of fingers on a glass-like a plate. The rate of rolling was from 70 to 90 stroking per minute in order to have a 3-4 mm dia.
- If thread's diameter is brought down below 3mm without the appearance of any cracks, it implies that the water content in it is more than its plastic limit. The soil was rubbed down to reduce the moisture content and rolled again into a thread.

- The process of flip-flop rolling and rubbing was repeated until the thread breaks down.

- The pieces of broken down soil thread were collected and kept in the petri dish whose weight was noted to measure the moisture content. Before that weight of petri dish was noted.

- Afterwards, the sample was dried for one day, and dried weight of sample and petri dish was taken.

- The similar process was repeated thrice with novel samples of plastic clay each time.

Rolling limit of clay can be measured from the following relation.

$$\% \text{ moisture content} = ((W_2-W_3)/(W_2-W_1)) \times 100$$

Where,

W_1= weight of empty petri dish

W_2= weight of petri dish and sample before drying.

W_3=weight of petri dish and sample after drying

4.5 GREEN SAMPLE PREPARATION

After proper homogenization which was done in porcelain mortar and pestle by continuous mixing for one hour for each batch and plastic limit for each batch was measured, the each batch was mixed with water according to their respective plastic limit.

Each batch was mixed, rolled and rubbed down to have uniform clay lump. Afterwards, small lumps were taken and placed on the top of the cleaned and oiled surface of the plate to press and cut the lump in order to make desired shape of a brick. Then initial length of 2 cm was printed on each brick samples.

After preparation of brick samples, they were taken to be dried at 100 ± 10^0C for 1 day.

4.6 DRYING SHRINKAGE

Drying shrinkage is defined as the abbreviating of a hardened solidified mixture because of the passing of capillary water. Before the solidified mixture is thrown to any type of loading, this shrinkage induces an increment in tensile stress, which can direct to cracking, internal warping and deflection.

Drying shrinkage is hooked upon many factors. These factors consider the proportions and properties of the components, manner of mixing, amount of wet when curing, drying environment, etc.

Drying shrinkage was measured by measuring the length of the sample after drying. Hence, drying shrinkage can be formulated as follows

$$\text{Drying shrinkage (\%)} = ((l_0 - l_1)/l_0) \times 100 \qquad \ldots.$$

Where,

l_0 = initial length of sample

l_1 = final length of sample

4.7 FIRING

Dried brick samples were fired in an electric furnace at 950^0C, 1050^0C, 1150^0C, 1200^0C and 1250^0C with a soaking time of 4 hours. The rate of heating throughout firing was very slow. The brick samples were heated from room temperature to 450^0C for 2 hours at a rate of 5^0C/minute. Then it is heated 950^0C and more than that for 2 hours at a rate of 3^0C/minute. The samples were cooled gradually and slowly. Afterwards, these were extracted for further characterisation.

4.8 FIRING SHRINKAGE

The firing temperature is a cardinal component that affects shrinkage in the firing process. Greater shrinkage causes the demolition of bricks both at firing and drying stages of output. Shrinkage in blocks occurs because of evaporation of chemically and mechanically bound water present in it.

Firing shrinkage was measured by measuring the length of the sample after firing. Hence firing shrinkage can be formulated as follows

$$\text{Firing shrinkage (\%)} = ((l_0 - l_1)/l_0) \times 100 \qquad \ldots.$$

Where,

l_0 = initial length of sample after drying

l_1 = final length of sampler after firing

4.9 APPARENT POROSITY

Apparent Porosity (AP) for all samples was computed with the help of the Archimedes' principle. The weights of the sintered products were noted and afterwards soaking the samples in water was done which was done by Vacuum method. The weight of the samples i.e. suspended weight(S) was noted. Subsequently surface water was removed from each sample to measure the soaked weight (W). Apparent Porosity was calculated using the relationship that is given below:

$$\text{Apparent Porosity} = \left(\frac{W-D}{W-S}\right) \times 100$$

Where,

W = Soaked Weight

D = Dry Weight

S = Suspended Weight

4.10 BULK DENSITY

Bulk density for all samples was computed with the help of the Archimedes' principle. The weights of the sintered products were noted and afterwards soaking the samples in water was done which was done by Vacuum method. The weight of the samples i.e. suspended weight(S) was noted. Subsequently surface water was removed from each sample to measure the soaked weight (W). Bulk density was calculated using the relationship that is given below

$$\text{Bulk density} = \left(\frac{D}{W-S} \right) \times 100$$

Where,

W = Soaked Weight

D = Dry Weight

S = Suspended Weight

4.11 WATER ABSORPTION

Water absorption for all samples was computed with the help of the Archimedes' principle. The weights of the sintered products were noted and afterwards soaking the samples in water was done which was done by Vacuum method. The weight of the samples i.e. suspended weight(S) was noted. Subsequently surface water was removed from each sample to measure the soaked weight (W). Water absorption was calculated using the relationship that is given below

$$\text{Water absorption} = \left(\frac{W-D}{D} \right) \times 100$$

Where,

W = Soaked Weight

D = Dry Weight

S = Suspended Weight

4.12 FLOW CHART OF THE PROCESSES FOLLOWED

Processes, as well as different characterization steps that were developed in this project, are shown in Fig 4.1.

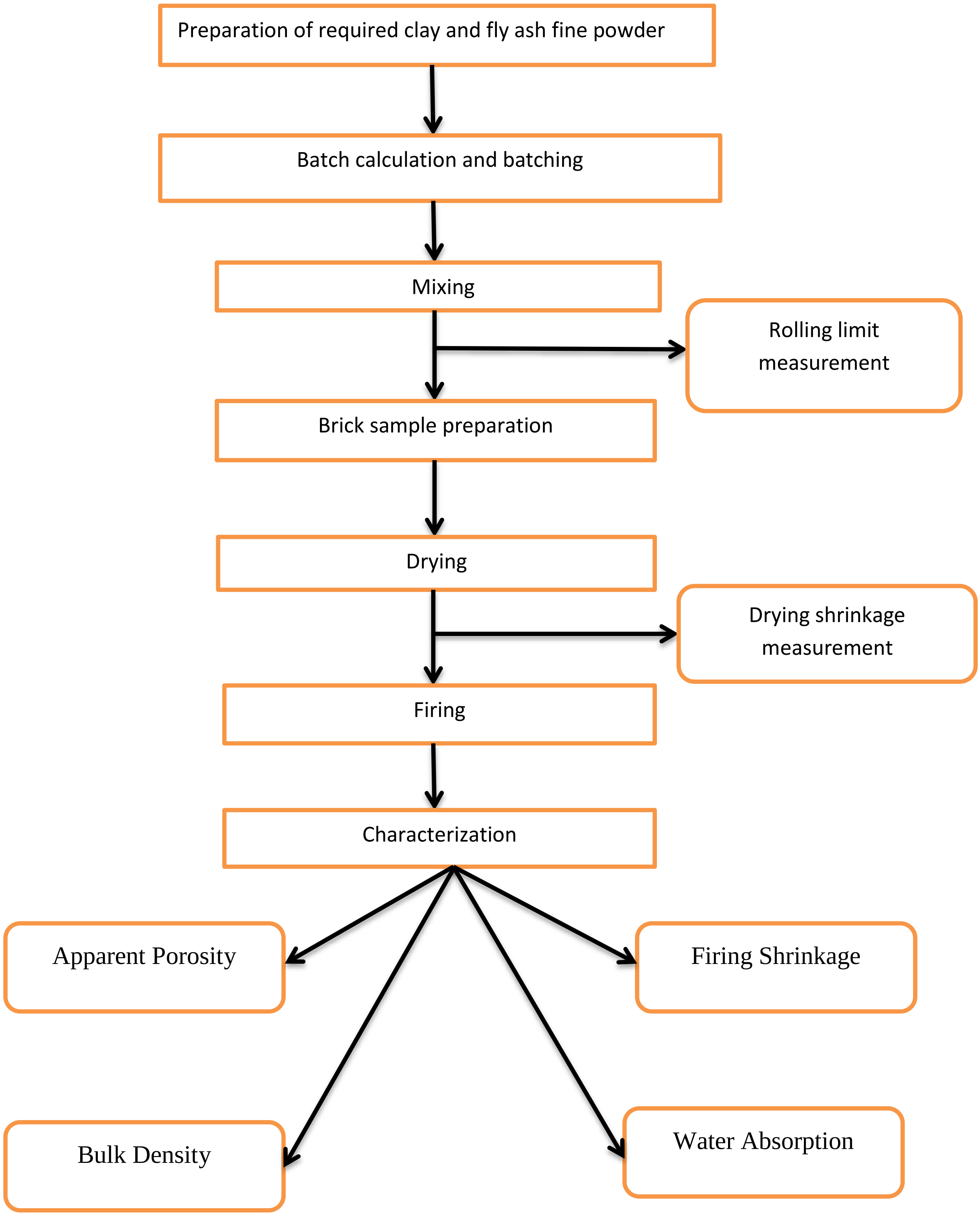

Fig 4.1 flowchart for brick samples preparation

CHAPTER 5

RESULTS AND DISCUSSION

5.1 ROLLING LIMIT

The variation of rolling limit (minimum water content needed to show plasticity) of the samples as a function of fly ash content of the batches is shown in fig 5.1

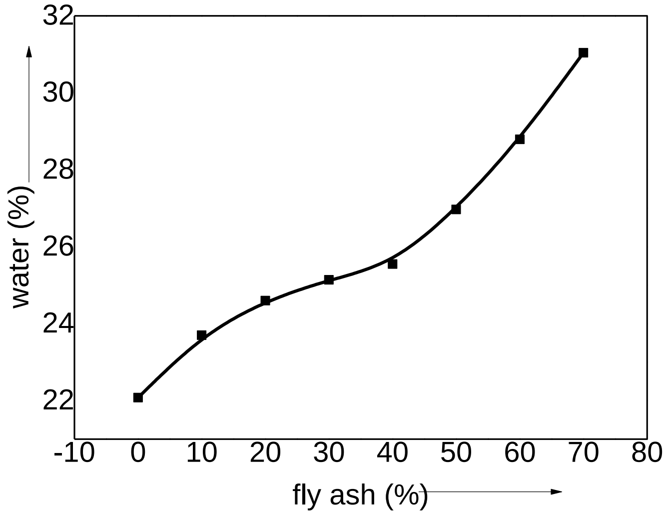

Fig 5.2 R*olling limit of the samples as a function of the fly ash content.*

It could be noted from the figure that with the increase in the fly ash content of the batches the minimum water needed to show plasticity i.e. rolling limit increases. It could also be described that initially when no fly ash was added to clay sample the rolling limit was just 22.1% water. The rolling limit started to increase slowly up to the addition of 40% of non-plastic fly ash component to clay. Then it increases sharply up to the addition of 70% fly ash.

70% of fly ash addition was just possible to roll. The addition of fly ash above 70% in a batch was not possible to be rolled because of the low plastic material present, which is helpful for rolling.

Fly ash is one of the residues of a combustion process. It is also known as flue-ash which are very fine particles that flow with flue gas. It undergoes the rapid air-cooling. Due to rapid cooling few minerals do not get time to crystallize and become amorphous in nature leading to having Al-Si glassy phase. Hence, it becomes non-plastic in nature, and it has no ability to absorb water. Fired clay is of two type i.e. plastic clay and non-plastic clay. The present study is concerned about only plastic fired clay. Water is needed to develop plasticity by increasing the flowability. More is the plastic material less water is required to roll. As the amount of fly ash content increases in the batches the amount of plastic content i.e. clay amount decreases. Hence, more water is needed to roll the batch containing more non-plastic fly ash content. Hence rolling limit increases with the increase in fly ash content.

5.2 DRYING SHRINKAGE

The variation of drying shrinkage of the samples as a function of fly ash content of the batches is shown in fig 5.2

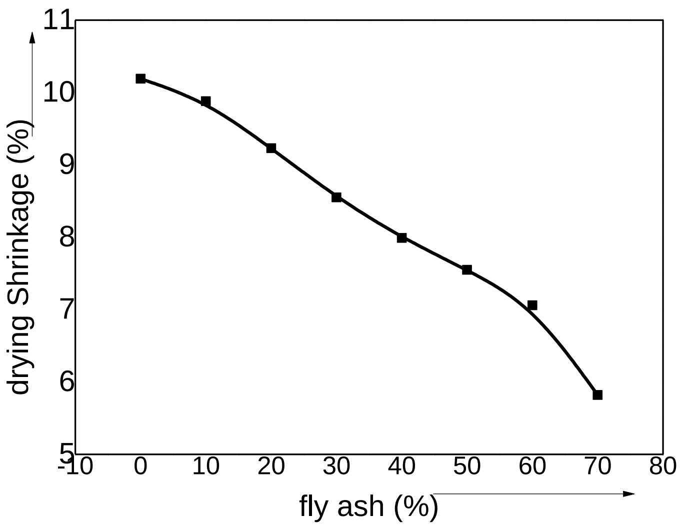

Figure 5.2 Drying shrinkage of the samples as a function of fly ash content.

Drying shrinkage decreases with the increase in the fly ash content in the batches, which is examined from the figure. When fly ash is not added to the batch, the drying shrinkage is

10.2%. It decreases gradually and reaches to a shrinkage value of 5.8% when fly ash content is 70% in the batch. Shrinkage of batches containing more than 70% of fly ash cannot be measured because of lack of handling strength. Handling strength increases with increase in plastic component i.e. in the sample. The drying shrinkage decreases almost linearly with the increase in fly ash content in batches.

Fly ash acts as filler i.e. anti-shrinkage material in the sample whereas clay undergoes shrinkage as it is plastic in this work. When water is added to sample, some water forms film over the clay surface and that water helps to have shrinkage in the samples. Some water goes to the interstitial spaces of fly ash, and that water is not helpful to have shrinkage in the body. Much water forms film over clay surface when sample contains more amount of clay leading to more shrinkage in the sample whereas much water goes into the interstitial space when fly ash content is more in the sample which results less shrinkage in the body. Hence drying shrinkage decreases with increase in fly ash content of the batches.

5.3 FIRING SHRINKAGE

The variation of firing shrinkage of the samples as a function of temperature and fly ash content of the batches is shown in fig 5.3(a).

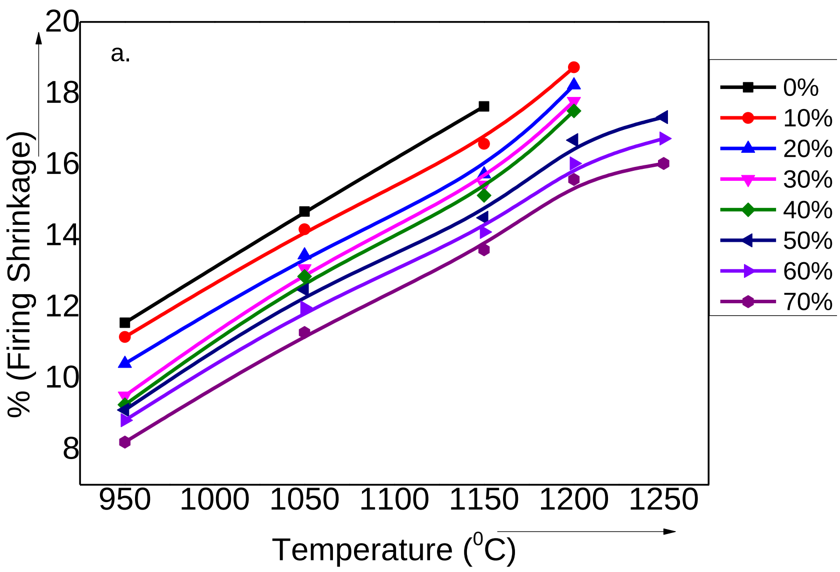

Figure 5.3(a) Firing shrinkage of the samples as a function of temperature and fly ash content.

It could be noted from the figure that firing shrinkage decreases with the increase in the firing temperature for all the brick samples examined. It can also be discovered that firing shrinkage decreases with the increase in fly ash content of the batches.

The increment in temperature helps the diffusion rate to increase leading to enhance the removal of pores of the body. More and more pores are removed from the body by increasing the temperature of the sample. Pore removal is related to densification and densification is linked to shrinkage. Means more is the pore removal more is the densification and more is the shrinkage. Our present work consists of fired clay and fly ash. Fired clay forms more liquid at 1150-1200 ^{0}C due to the presence of different impurities in it. The liquid phase thus formed enhances more densification either by liquid phase sintering or vitrification mechanism. So firing shrinkage increases rapidly after 1150°C whereas shrinkage increases slowly from 950°C to 1150°C. It is because melting temperature of most of the impurities is above 1100°C. As a result firing shrinkage increases with the rise in temperature.

The variation of firing shrinkage of the samples as a function of the fly ash content of the batches and temperature is shown in fig 5.3(b).

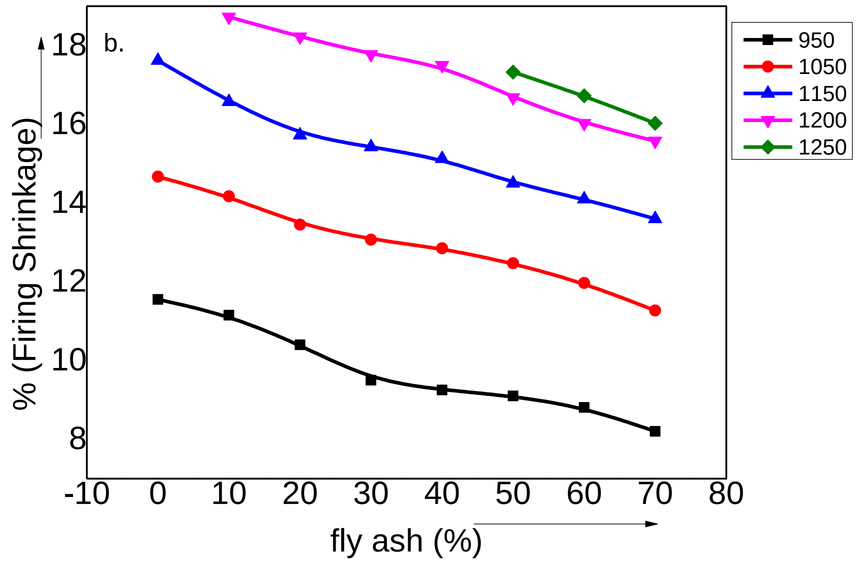

Figure 5.3(b) Firing shrinkage of the samples as a function of the fly ash content and temperature.

The increment in the firing temperature causes firing shrinkage to decrease for all the brick samples studied. It can also be known from the graph that firing shrinkage decreases with the increase in fly ash content of the batches.

Fly ash has a fusion temperature higher than that of fired clay. Hence fly-ash acts as filler i.e. anti-shrinkage component in the composition. As discussed above densification in the present system is mostly governed by liquid phase sintering, vitrification and viscous flow (arising from the presence of glassy phase in the fly ash). The liquid phase is formed from the impurities present in the fired clay. Hence with the increase in fly ash content clay amount in the sample decreases leading to reduce the number of impurities. So less liquid phase is created due to the presence of high amount of fly ash which leads to low shrinkage in the body. As a result firing shrinkage decreases with the increase in fly ash content in the batch.

5.4 APPARENT POROSITY

The variation of apparent porosity of the samples as a function the temperature and fly ash content of the batches is shown in fig 5.4(a).

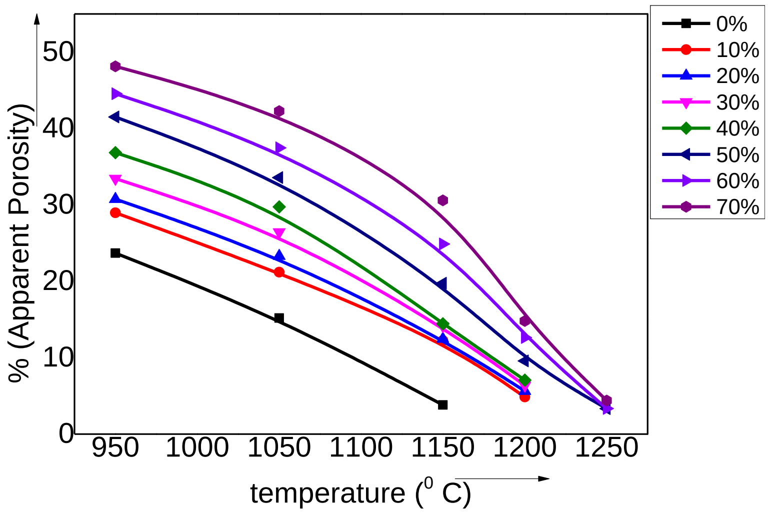

Figure 5.4(a) Apparent porosity of the samples as a function of temperature and fly ash content.

From the figure, it could be seen that a decrease in apparent porosity occurs with an increase in the firing temperature for all the samples examined. The direct correlation could be observed between the fly ash content with the apparent porosity of the samples. Here it can be explained that apparent porosity decreases slowly up to the temperature of 1150 ^{0}C then it drops sharply. Apparent porosity is related to densification of the body. Pore removal increases with the rise in densification and increase in densification take place with increasing temperature. Hence, apparent porosity decreases with the rise of densification. Pore removal is provided by diffusion. More will be diffusion less will be the apparent porosity. Fly ash and fired clay are contained in the samples. Above 1150 ^{0}C, fired clay forms liquid phase because of the presence of different impurities. This liquid phase helps to have densification leading to decrease in apparent porosity. Hence, apparent porosity decreases with increase in temperature.

The variation of apparent porosity of the samples as a function of the fly ash content of the batches and temperature is shown in fig 5.4(b).

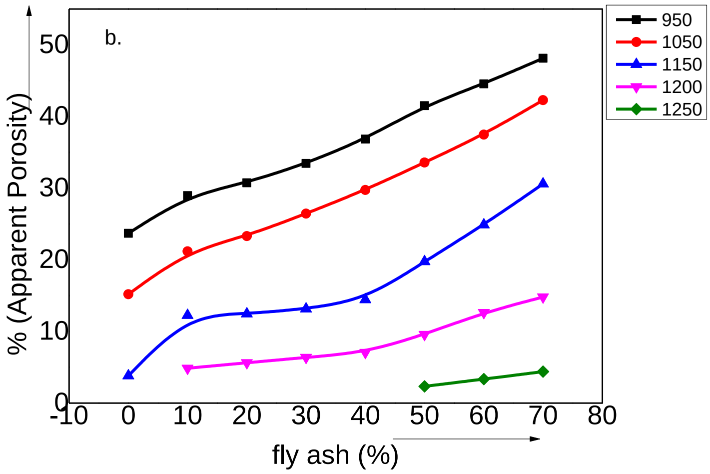

Figure 5.4(b) Apparent porosity of the samples as a function of the fly ash content and temperature.

Some facts can be understood from the above graph that apparent porosity rises as the fly ash content rises for all the samples examined. The inverse correlation could be observed between the firing temperature and the apparent porosity of the samples.

Fly ash acts as anti-shrinkage material i.e. filler because fusion temperature of fly ash is more than that of fired clay. Due to the presence of impurities in fired clay samples forms liquid as temperature increases. The liquid goes into the interstitial space of fly ash. Hence, more is the amount of fly ash in the batch more is the interstitial space in the body leading to more liquid going into interstitial space. So fewer amounts of liquid forms film over clay particles and that liquid is helpful for better densification and shrinkage leading to higher apparent porosity with the increase in the quantity of fly ash in the composition. In addition to the above reason, the sample with the larger amount of fly ash forms less liquid due to fewer amounts of impurities in it. That is led to having less densification and high apparent porosity. In this way, an increase in fly ash amount helps the body to have higher apparent porosity.

5.5 WATER ABSORPTION

The variation of water absorption of the samples as a function of temperature and fly ash content of the batches is shown in fig 5.5(a).

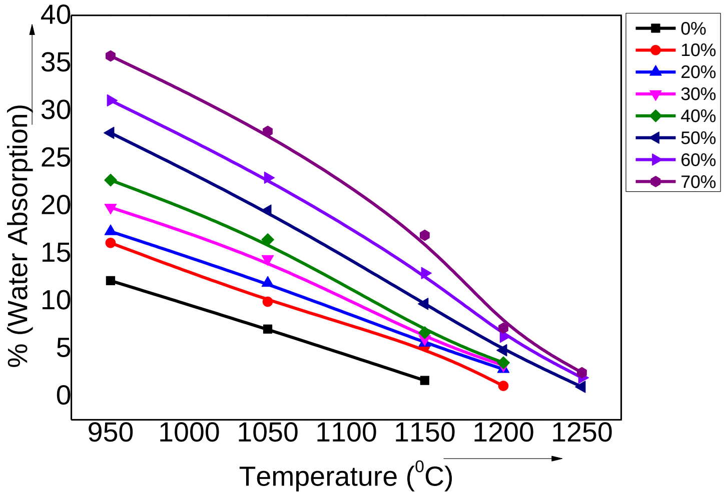

Figure 5.5(a) Water absorption of the samples as a function of temperature and fly ash content.

It could be noted from the above figure that the decrease in water absorption takes place, according to the increase in the firing temperature for all the samples examined. The increment in fly ash content leads to having an increase in water absorption of all samples studied yet. Here it can be explained that water absorption decreases slowly up to the temperature of 1150 0C then it falls sharply. These things are explained as follows.

Water absorption is due to the presence of pores in the samples. More is the pore more is the water absorption in the sample. Diffusion is the cause for the elimination of pores forms the sample. Diffusion rate increases with the increase in temperature leading to more removal of the pore. It leads to having less water absorption. Diffusion also depends upon liquid phase, which depends upon impurities. With the increase in fly ash content, impurities of fired clay decreases. Hence less liquid phase is formed in higher fly ash samples leading to increasing water absorption. After 1150 ^{0}C water absorption decreases sharply because almost all impurities are converted into liquid phase leading to better densification.

The variation of water absorption of the samples as a function of the fly ash content of the batches and temperature is shown in fig 5.5(b).

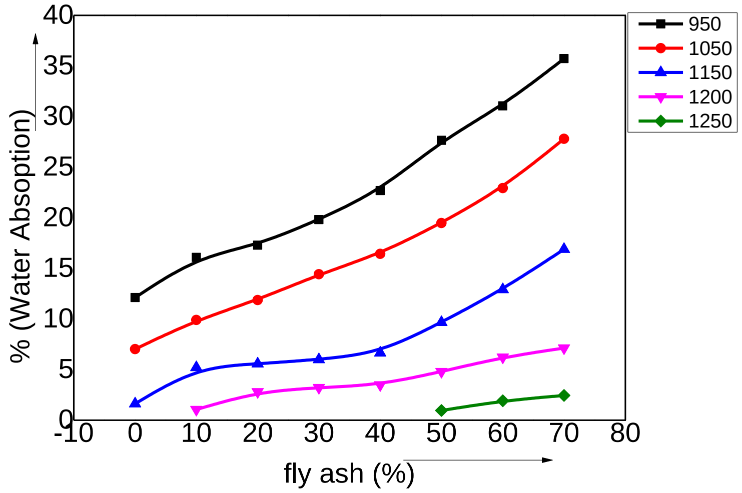

Figure 5.5(b) Water absorption of the samples as a function of the fly ash content and temperature.

After observing the figure, some conclusion can be noted that water absorption rises as the fly ash content rises for all the samples experimented. The inverse correlation could be observed between the firing temperature and the water absorption of the samples.

Water absorption is dependent upon the fly ash amount present in the body and fly ash act as anti-shrinkage i.e. filler material because the fission temperature is more than that of the fired clay. Densification is due to liquid phase sintering, vitrification, and viscous flow (happens because of the glassy phase present in the fly ash). More is the densification lesser is the water absorption. Densification depends upon the amount of liquid phase present in the sample. Densification increases with the rise in clay content which provides impurities which give liquid phase. Hence densification decreases with the increase of the fly ash content as clay amount decreases. In another way, the result can be explained. As fly ash is the anti-shrinkage material, the liquid formed at high temperature goes into the inter-particle space of fly ash leading to less densification. S water absorption increases with the increase in fly ash as inter-particle space in fly ash increases.

5.6 BULK DENSITY

The variation of bulk density of the samples as a function of temperature and fly ash content of the batches is shown in fig 5.6 (a).

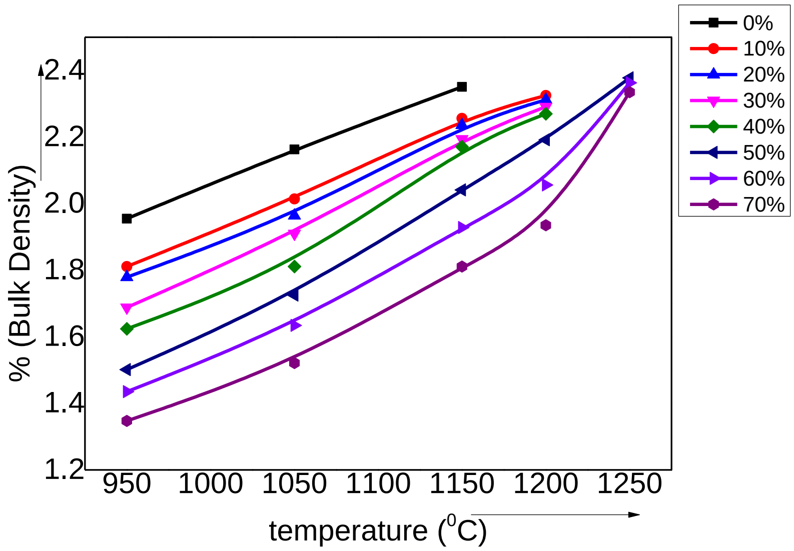

Figure 5.6(a) Bulk density of the samples as a function of temperature and fly ash content.

From the figure, it could be observed that the increase in bulk density leads to the increase in the firing temperature for all the samples studied. The inverse correlation could be found between the fly ash content with the bulk density of the samples. Here one more thing can be pointed out that bulk density increases slowly up to the temperature of 1150 ^{0}C then it increases sharply.

Bulk density is related to densification of the body. Pore removal increases with the increase in densification and increase in densification take place with increasing temperature. Hence, bulk density increases with the rise of densification. Pore removal is provided by diffusion.

More will be diffusion more will be the bulk density. Fly ash and fired clay are contained in the samples. Above 1150 ^{0}C, fired clay forms liquid phase because of the presence of different impurities. This liquid phase helps to have densification leading to increasing in bulk density. Hence, bulk density increases with increase in temperature.

The variation of bulk density of the samples as a function of the fly ash content of the batches and temperature is shown in fig 5.6 (a).

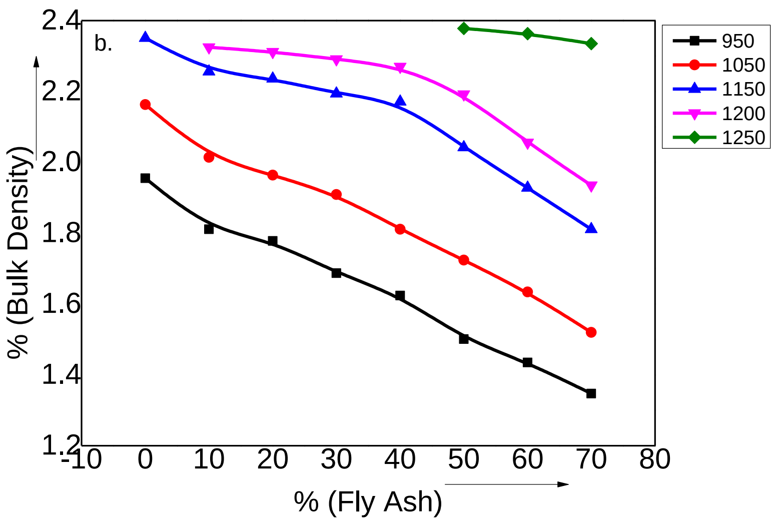

Figure 5.6 (b) Bulk density of the samples as a function of fly ash content and temperature.

Some facts can be understood from the above graph that the bulk density falls as the fly ash content rises for all the samples examined, and it increases with the increase in the applied temperature.

Fly ash acts as anti-shrinkage material i.e. filler because fusion temperature of fly ash is more than that of fired clay. Due to the presence of impurities in fired clay samples forms liquid as temperature increases. The liquid goes into the interstitial space of fly ash. Hence, more is the amount of fly ash in the batch more is the interstitial space in the body leading to more liquid going into interstitial space. So fewer amounts of liquid forms film over clay particles and that liquid is helpful for better densification and shrinkage leading to having lower bulk density with the increase in the quantity of fly ash in the composition. In addition to the above reason, the sample with a higher amount of fly ash forms less liquid due to fewer amounts of impurities in it. That's led to having less densification and less bulk density. In this way, an increase in fly ash amount helps the body to have lower bulk density.

By using the figure of apparent porosity with respect to temperature, a new graph can be extrapolated to know the sintering temperature of the different batch having constant apparent porosity. Here fig 5.7 represents the variation of sintering temperature as a function of fly ash content for 3.23% of apparent porosity and 14.9 % apparent porosity.

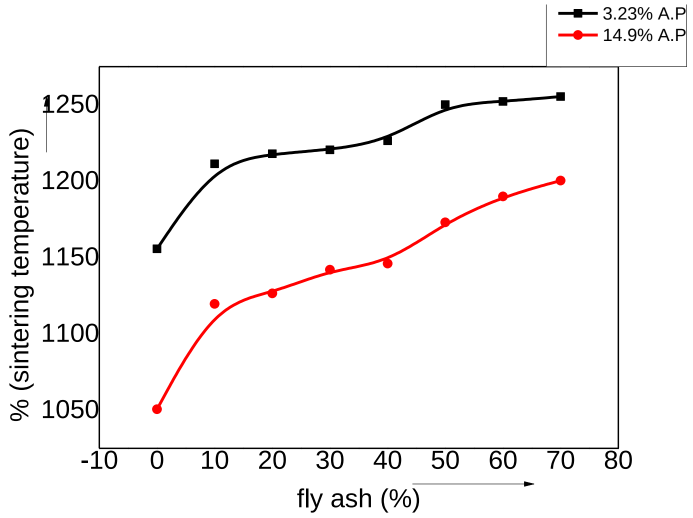

Figure 5.7 sintering temperature as a function of fly ash content for 3.23% of apparent porosity and 14.9 % apparent porosity.

From the above graph, it can be concluded that sintering temperature increases with the increase in fly ash content that is observed in all samples. One more conclusion can be extracted from the graph i.e. sintering temperature will be more if lower apparent porosity is needed. By using an above graph, we can easily get the sintering temperature of any batch at any demanding apparent porosity.

CONCLUSION

1. Rolling limit of samples increases with the increase in fly ash content in the composition as fly ash is non-plastic in nature.
2. As the fly ash content increases in the batch drying shrinkage decreases gradually. It is because fly ash acts as filler i.e. anti-shrinkage material.
3. More is the firing temperature more is the firing shrinkage, and firing shrinkage falls with the increase in fly ash content in the body.
4. Similarly, water absorption and apparent porosity decreases with the increase in firing temperature and increases with increase in fly ash content whereas the relation is reversed for bulk density.
5. Fly ash plays a significant role in achieving a particular apparent porosity.
6. Fly ash increases the sintering temperature of the system because it acts as anti-shrinkage material.

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